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A Survey of Amphibians at the Smithsonian Environmental Research Center, Anne Arundel County, Maryland

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ABSTRACT

During a two-year amphibian inventory at the Smithsonian Environmental Research Center (SERC) in Anne Arundel County, Maryland, we documented approximately 93% (13/14) of the county's frog and toad fauna and 56% (5/9) of the salamanders. We also provide a general framework for monitoring difficult-to-detect calling anurans (Wood Frog and Eastern Spadefoot) and Spotted Salamander at SERC. In addition, we incidentally documented 53% (21/40) of the county's reptiles. The known herpetofauna of SERC consists of 39 species.

Key words: amphibian, anuran call surveys, amphibian monitoring, frogs, toads, salamanders.

INTRODUCTION

Amphibians are part of a global biodiversity crisis (Blaustein et al., 1994). One third of amphibian species are threatened with extinction, and nine species have gone extinct since 1980 (IUCN, 2015). Reasons for population declines and extinction include natural population fluctuations and a complex of anthropogenic factors, including habitat loss, pollution, climate change and chytridiomycosis, a disease of the skin caused by a pathogenic fungus *Batrachochytrium dendrobatidis* (Davidson et al., 2003; Young et al., 2007; IUCN, 2015). Amphibians are particularly susceptible to habitat destruction and chytridiomycosis in part because they have relatively thin, permeable skin that serves as a respiratory organ and (most typically) a biphasic life history that includes a gilled aquatic larval phase and a terrestrial adult form (Blaustein & Wake, 1995; Vitt & Caldwell, 2013). Consequently, amphibians are among the most sensitive vertebrates to various forms of environmental disturbances, and are considered to be indicators of environmental health (Wyman, 1990). Depending on the species, one sexually mature female may produce hundreds or thousands of embryos, potentially contributing substantial amounts of biomass (in the form of larvae and newly metamorphosed subadults) to their resident ecosystems annually (Wright & Wright, 1949; Vitt & Caldwell, 2013). Thus, amphibians are critical trophic links between aquatic and freshwater ecosystems, and local extinctions can in turn lead to ecological imbalances (Whiles et al., 2006). Due to their ecological importance, environmental sensitivity, and documented declines, localized and large-scale inventory and long-term amphibian monitoring programs have been implemented throughout North America (Weir & Mossman, 2005; Weir et al., 2009; see Cook et al., 2011).

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The Smithsonian Environmental Research Center (SERC) in eastern Maryland serves as a natural laboratory for long-term ecological research. The Center seeks to understand the impacts of climate change, invasive species, anthropogenic land use, pollution, and fishery harvest on native flora and fauna (SERC, 2015a). However, aside from selected herbivore-plant interactions, relatively little is known of the non-estuarine fauna of SERC (but see Heyer 1976, 1979; Lynch, 1984; Szlavecz et al., 2011; Cook-Patton et al., 2014a, b). We report the results of an amphibian inventory and provide baseline data that can be used to establish a long-term amphibian monitoring program at SERC.

MATERIALS AND METHODS

Study Area and Site Selection

SERC (38°33'17.57"N; 76°33'14.29"W) consists of approximately 1,477 ha of hardwood-dominated forest, ponds, creeks, rivers, tidal marshes, and 19.3 km of protected shoreline along the Rhode River and upper Chesapeake Bay in Anne Arundel County, Maryland (SERC, 2015b; Fig. 1). Forests at SERC can be broadly classified into three main types: (1) the majority (~85%) is a Tulip-poplar (*Liriodendron tulipifera*) association; (2) a moist lowland assemblage, comprised of American sycamore (*Platanus occidentalis*), ash (*Fraxinus* spp.), elms (*Ulmus* spp.), river birch (*Betula nigra*), and other woody vegetation along freshwater streams; and (3) a somewhat xeric assemblage that fringes tidal marshes, consisting of chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), black gum (*Nyssa sylatica*), mountain laurel (*Kalmia latifolia*), blueberries (*Vaccinium* spp.) and other woody vegetation. Like much of the eastern U.S., SERC's forest age and structure reflect historical agricultural activities and local history. The land that now comprises SERC's main campus was mostly fallow from the end of the Civil War to approximately 1915, when it was used as a dairy with grazing pastures and fields for feed production until 1945. Thus, the majority of SERC's contemporary forests are ca. 70-150 years old (Higman, 1968; McMahon et al., 2010, G. Parker, SERC pers. comm.).

Freshwater inputs into the Rhode River are primarily from the North Fork Muddy Creek, South Fork Muddy Creek, and their lower order streams. These streams are associated with several swamps, beaver impoundments, and vernal wetlands which range from small, tannin-rich, short-hydroperiod ephemeral wetlands, to larger and clearer-water permanent ponds. We selected 15 (Fig. 1) of these wetlands to sample. Site selection was not random, and was based in part on accessibility.

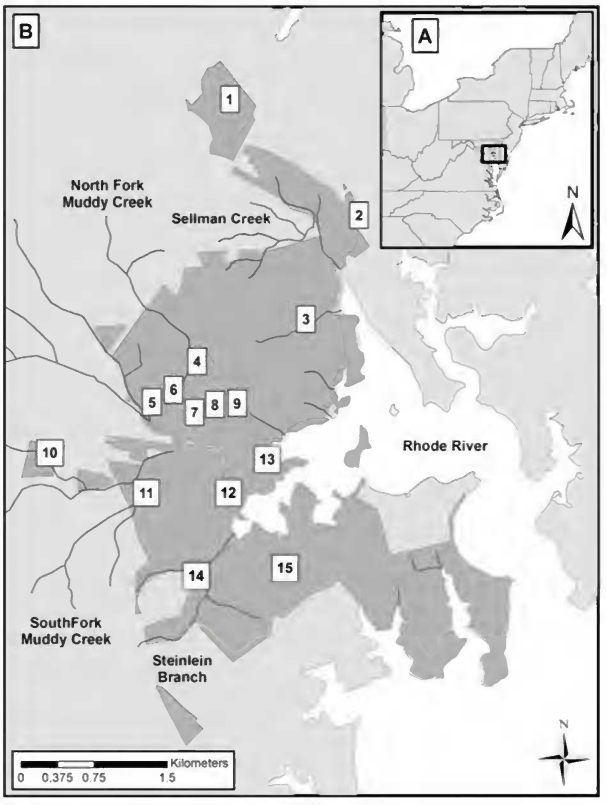

Fig. 1. Map of anuran calling survey sites, 2014-2015. Dark shaded areas represent SERC with numbers indicating locations of surveys sites: (1) Glebe Bog, (2) Camp Letts Pond, (3) Contees Wetland/Cypress Swamp, (4) Beaver Pond, (5) North Fork (6) Snake House Wetland, (7) Construction Pond, (8) Mathias Wetland, (9) Retaining Pond, (10) Mill Swamp, (11) O'Neill Marsh (12) Hog Island Complex, (13) Fox Point, (14) Horseshoe Bog, and (15) CO2 Marsh.

Anuran Call Surveys

We conducted weekly anuran (frog and toad) call surveys between 21 March and 5 September 2014 and 2015 following North American Amphibian Monitoring Program guidelines (Weir & Mossman, 2005). Sampling began after sunset and consisted of listening for calling anurans for 5 min at each site. Most surveys began well after sunset, but before 0100 h ($\bar{x}$ = 116.4 min after sunset; SE = 4.69). Each detected species was assigned an ordinal calling index value (scale of 1-3) based on the degree of overlap between calls (Weir & Mossman, 2005). Undetected species were assigned a rank of "0" for that survey. During each call survey, we also recorded surface water and air temperatures

with fixed armor casting pocket thermometers, and sky and wind conditions, and noise interference levels based on protocols in Weir & Mossman (2005). We stopped conducting anuran call surveys at sites if surveys resulted in non-detections for all species for four consecutive weeks.

Egg Mass Counts

Wood Frogs (*Lithobates sylvaticus*) often vocalize diurnally and oviposit globular and conspicuous egg masses in permanent and ephemeral wetlands (Wright & Wright, 1949; Berven 1990; Klemens, 1993). Thus, egg mass counts are a widely used technique to monitor their populations (Berven, 1990; Crouch & Paton, 2000; Cook & Boland, 2005). Spotted Salamander (*Ambystoma maculatum*) oviposits similarly (Wright & Allen, 1909), and egg mass counts are also used to monitor their populations (Brodman, 1995, 2005; Egan & Paton, 2004; Petranka et al., 2003; Cook & Boland, 2005). We conducted three rounds of egg mass counts via the maximum daily count method (Cook & Boland, 2005) at seven wetlands during known breeding periods after the onset of appropriate temperatures (Crouch & Paton, 2000; Egan & Paton, 2004; Brown & Jung, 2005). To maximize visibility, we only conducted counts while wearing polarized glasses during relatively clear, calm weather.

Additional Sampling Methods

Due to the explosive breeding behavior of the Eastern Spadefoot (*Scaphiopus holbrookii*) (Hansen, 1958), there is a greater chance of not detecting this species with call surveys (Cook et al., 2011). Therefore, we augmented call surveys by using throw trapping (quantitative enclosure sampling), [see Shaffer et al., 1994] combined with a removal sampling [Hayek, 1994]) as means of detecting and quantifying Eastern Spadefoot tadpole abundance. The throw trap was a 1 m^3 box with fine mesh screening attached on four sides. The top and bottom of the trap remained unscreened. Before sampling we created cross-sectional and longitudinal transects in the wetland which we used to guide tossing of the trap. Every two meters along each transect we tossed the trap into the water (open sides down and up). Using an aquatic D-frame dip net, we scooped out larvae, counted them, and temporarily removed them from the wetland in five-gallon buckets until we made it completely across both transects.

We used time-constrained searches (Scott & Woodward, 1994) to identify salamanders and anurans that were undetected with egg mass counts and anuran call surveys. We began each search at an anuran call survey site and walked away from the starting point haphazardly looking for herpetofauna, both outwardly visible and beneath debris, for 45 minutes. If detected during time-constrained searches, or otherwise incidentally while traveling between sites, we considered a given species "present." We documented species at sites other than at habitats adjacent to call survey sites, so those sites also appear in Table 1.

We calculated descriptive statistics with Minitab version 16 and Microsoft Excel 2013. Maps were created in ArcGIS 10.1. We based common names, and generic and specific epithets of herpetofauna on Crother (2012).

RESULTS

Anuran Call Surveys

We conducted a total of 503 anuran call surveys at 15 sites between 13 March and 5 September 2014 and 2015, documenting 13 species. The Construction Pond, Mathias Wetland, Retaining Pond, Beaver Pond, and Horseshoe Bog contained the most species. By contrast, only one species was detected at Fox Point, which also had the fewest detections of calls. Surveys conducted at the Mathias Wetland and Mill Swamp yielded the highest proportions of detections (Tables 1 and 2). Onset of calling occurred earliest in Spring Peeper (*Pseudacris crucifer*) and Wood Frog (on our first survey; 72nd and 73rd day of the year), and latest in Green Treefrog (*Hyla cinerea*; 114th day of the year). We detected full choruses (calling index values = 3) in all species except Upland Chorus Frog (*Pseudacris feriarum*) and Gray Treefrog (*Hyla versicolor*). We only detected Eastern Spadefoot while in full chorus, and only in 2014 (Table 3).

Egg Mass Counts, Throw Trapping, Time Constrained Searches, and Incidental Encounters

Between 24 March and 18 April 2015, we conducted egg mass counts at seven sites, yielding maximum counts of 977 Wood Frog and 209 Spotted Salamander egg masses. The Beaver Pond (a large permanent wetland) had the most Spotted Salamander egg masses (31% of the total), and Snake House Pond (a relatively small, short hydroperiod wetland) contained the fewest (0.01%). Over half of Wood Frog egg masses (54.2%) were located at Horseshoe Bog (a large river-fed seasonal wetland), whereas only one egg mass was found at Snake House Pond (Table 4).

We captured 3,826 Eastern Spadefoot tadpoles at the only known breeding site (Camp Letts Pond) with one round of 11 throws of a single trap in 2014. We did

Table 1. Detections of amphibians and reptiles at SERC study sites. An "x" = detected, a dash = not detected. Site abbreviations not identified in Appendix 1 are: EDU (Education Building), located ~0.75 km NNE of Fox Point. See Appendix 2 for species abbreviations.

Species	BEPO	CALE	CO2	COPO	CONTE	EDU	GLEBE	FOPO	HOMA	HOVE	HOSH	MATH	MISW	NOFR	ONEIL	RETAIN	SNHO
AMTO	X	-	X	X	-	X	X	-	X	X	X	X	X	X	X	-	X
BOTU	X	-	-	X	-	X	-	-	-	-	-	-	-	-	X	-	-
BUFR	X	-	-	X	X	-	X	-	-	-	-	X	X	-	-	X	X
CGTF	X	X	-	X	X	X	X	-	X	-	X	X	X	-	X	X	-
CHFR	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-	-	-
CRFR	X	-	-	X	X	-	-	-	-	-	X	X	X	X	X	X	X
DBTE	-	-	X	-	-	X	-	X	X	-	-	-	-	-	-	-	-
FLSK	X	-	X	X	-	X	-	-	X	-	-	X	-	-	X	X	-
FTSA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-
GASN	X	-	-	X	X	-	-	-	-	-	-	-	-	-	-	X	X
GRFR	X	X	X	X	X	-	X	-	-	X	X	X	X	X	X	X	X
GRTF	X	-	-	X	X	-	-	-	X	-	-	X	X	-	-	-	X
KISN	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
MASA	X	-	-	X	X	-	-	-	-	-	X	-	-	-	X	-	-
MUDT	X	-	-	-	X	X	-	-	-	-	-	-	-	-	-	X	-
MUSK	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NBSN	X	-	-	X	-	-	-	X	-	-	-	X	-	-	-	X	-
NGTF	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-	-
NWSN	X	-	-	X	-	X	X	X	X	-	-	-	-	-	-	X	X
PATU	X	-	X	X	-	-	-	X	X	-	-	-	X	-	-	X	-
PIFR	X	-	X	X	X	-	X	-	X	-	X	-	X	-	X	X	X
RACER	X	-	-	X	-	X	-	-	X	-	-	-	-	-	X	X	-
RASN	X	-	-	X	-	X	X	-	-	-	-	-	-	-	-	X	X
RBSA	X	X	-	-	X	-	X	-	X	-	X	-	-	-	-	-	X
RBTU	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-
RESL	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-
RGSN	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
RISN	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X
RNSN	X	X	-	X	X	-	-	-	X	-	-	-	-	-	-	-	-
RSNE	X	-	-	-	-	-	-	-	X	-	-	-	-	-	X	-	-
SESN	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
SLFR	X	X	X	X	X	X	X	X	X	-	X	X	X	-	X	X	X
SNTU	X	-	X	X	-	X	-	X	X	-	-	-	X	-	-	X	-
SPPE	X	X	X	X	X	X	X	X	X	-	X	X	X	X	X	X	X
SPSA	X	-	-	-	X	-	X	-	-	-	X	-	-	-	-	-	X
SPTO	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPTU	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	X
WOFR	-	X	-	X	X	-	X	-	-	-	X	X	-	-	X	-	-
WOSN	X	-	X	X	X	-	-	-	-	-	-	-	-	-	X	-	-

Table 2. Proportion of surveys yielding detections per study site at SERC. * = Documented after study period. See Appendix 2 for species abbreviations.

Site	AMTO	BUFR	CHFR	CGTF	CRFR	GRFR	GRTF	PIFR	SLFR	SPPE	SPTO	WOFR
Beaver Pond	0.04	0.68	-	0.08	0.48	0.72	0.20	0.20	0.24	0.32	-	*
Camp Letts Pond	-	-	-	0.21	-	0.21	-	-	0.21	0.50	0.14	0.07
CO2 Marsh	0.30	-	0.30	-	-	0.10	-	0.10	0.50	0.60	-	0.00
Construction Pond	0.16	0.36	-	0.32	0.36	0.64	0.20	0.12	0.36	0.28	-	0.08
Contees Wetland	-	-	-	0.13	-	0.20	-	0.07	-	0.40	-	-
Cypress Swamp	-	-	-	-	-	-	-	-	-	-	-	-
Glebe Bog	-	-	-	-	-	0.47	-	-	0.05	0.37	-	0.05
Fox Point	-	-	-	-	-	-	-	-	0.09	0.00	-	-
Hog Main	0.18	-	-	0.18	-	-	-	-	0.55	0.36	-	-
Hog Vernal	-	-	-	-	-	-	-	-	-	-	-	-
Horseshoe Bog	0.09	0.04	-	0.48	0.30	0.61	-	0.09	0.26	0.30	-	0.04
Mill Swamp	0.08	0.63	-	0.29	0.63	0.79	0.25	0.25	0.25	0.29	-	-
North Fork	-	-	-	-	-	-	-	-	0.25	0.38	-	-
O'Neill Marsh	0.15	-	-	0.25	-	0.60	-	0.25	0.30	0.35	-	0.05
Retaining Pond	-	0.67	-	0.21	0.46	0.67	-	0.08	0.04	0.29	-	-
Snake House Wetland	-	-	-	-	0.08	0.08	-	-	-	0.08	-	-

Table 3. Seasonal calling chronology of anuran species detected on CAS at SERC. Data are pooled from 2014 and 2015. Values are maximum calling index values calculated for each species during a given sampling period. See Appendix 2 for species abbreviations.

Sampling Period	AMTO	BUFR	CGTF	CHFR	CRFR	GRFR	GRTF	NGTF	PIFR	SLFR	SPPE	SPTO	WOFR
March 13-March 19	-	-	-	-	-	-	-	-	-	1	3	-	3
March 20-March 27	3	-	-	-	-	-	-	-	1	3	3	-	3
March 28-April 3	3	-	-	2	-	-	-	-	1	2	3	-	-
April 4-April 10	3	1	-	2	-	-	-	1	3	2	3	-	-
April 11-April-17	1	2	-	-	1	1	-	-	2	1	3	-	-
April 18-April25	1	2	3	-	-	1	-	1	-	2	3	3	-
April 26-May2	1	2	3	-	3	2	-	-	2	2	3	-	-
May 3-May 9	-	3	3	-	3	3	-	-	-	1	-	-	-
May 10-May 16	-	1	-	-	3	1	-	-	-	1	-	-	-
May 17-May 23	-	2	3	-	3	3	2	-	-	1	-	-	-
May 24-May 30	-	3	2	-	3	3	1	1	-	-	-	-	-
May 31-June 6	-	1	3	-	3	3	1	-	-	-	-	3	-
June 7-June 13	-	2	2	-	3	3	2	-	-	-	-	-	-
June 14-June20	-	2	2	-	3	3	2	-	-	-	-	-	-
June 21-June 27	-	1	2	-	3	3	1	-	-	-	-	-	-
June 28-July 4	-	1	1	-	3	3	3	-	-	-	-	-	-
July 5-July 11	-	1	1	-	3	3	1	-	-	-	-	-	-
July 12-July 18	-	1	1	-	2	3	2	-	-	-	-	-	-
July 19-July 25	-	1	-	-	-	1	-	-	-	-	-	-	-
July 26-Aug 1	-	1	-	-	-	1	-	-	-	-	-	-	-
Aug 2-Aug 8	-	1	1	-	1	3	-	-	-	1	-	-	-
Aug 9-Aug 15	-	1	-	-	-	1	-	-	-	-	-	-	-
Aug 16-Aug 22	-	1	-	-	-	1	-	-	-	-	-	-	-
Aug 23-Aug 29	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug 30-Sep 5	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4. Number of egg masses detected, grouped by species and site.

Site	SPSA	WOFR
Beaver Pond	65	2
Camp Letts Pond	26	87
CO2 Marsh	19	12
Contees Wetland	49	114
Horseshoe Bog	11	530
O'Neill Marsh	36	231
Snake House Wetland	3	1

not complete a second round of throws because the wetland dried just prior to sampling. The largest concentration of tadpoles appeared to be in the shallower regions toward the edge of the wetland. We did not find Eastern Spadefoot tadpoles or adults in 2015.

A total of 1,170 search minutes (19.5 hours) in 2014 and 2015 yielded three additional salamander species: Eastern Newt (*Notophthalmus viridescens*; 3 sites), Eastern Red-backed Salamander (*Plethodon cinereus*; 6 sites) and Marbled Salamander (*Ambystoma opacum*; 4 sites). Spotted Salamander was detected at five additional sites and one Four-toed Salamander (*Hemidactylium scutatum*) was found incidentally at a sphagnum-rich bog ca. 200 m northeast of O'Neill Wetland. All salamander species except the latter can be found at the Beaver Pond. Contees Wetland and Horseshoe Bog (both seasonal wetlands) contained three of these species.

DISCUSSION

Overview

SERC's main campus and additional parcels provide habitat for approximately 93% (13/14) of Anne Arundel County's anurans, and 56% (5/9) of its salamanders. We also incidentally documented approximately 53% (21/40) of the county's reptiles (Reed, 1956; MARA, 2015; Table 1). These numbers include sea turtles and historical records, but exclude documented non-natives. In total, 39 species were found, 28 of which can be found in or near the Beaver Pond. Although all species documented at SERC in this study can be found elsewhere in Anne Arundel County, Upland Chorus Frog, Eastern Spadefoot, and Four-toed Salamander are uncommon in the county. Upland Chorus Frog is under consideration for possible state listing (MARA, 2015). We heard choruses of this species at two adjacent, vernal sites (Horseshoe Bog and CO2 Marsh) along the south side of Rhode River (Fig. 1). Although this population appears to be small, we recommend continued monitoring and searches for additional Upland Chorus Frog breeding areas at SERC. The only breeding site (Camp Letts Pond) used by the Eastern Spadefoot identified in this study contains water for short periods after major rain events, and is the closest study site to sandier areas associated with Chesapeake Bay shorelines. The lone Four-toed Salamander documented in this study was found inside a rotting log in a boggy area close to the O'Neill Wetland. This species occurs in and around boggy ponds and floodplains, is almost always associated with sphagnum moss, and is patchily distributed even in areas with suitable habitat (Klemens, 1993). We recommend further targeted sampling of likely habitats to fully access the occurrence of Four-toed Salamander at SERC.

Although not documented in this study, Northern Two-lined Salamander (*Eurycea bislineata*), Northern Dusky Salamander (*Desmognathus fuscus*), and Mud Salamander (*Pseudotriton montanus*) were purportedly detected at SERC in the early 1980s (J. Lynch, SERC, unpubl. data). Additionally, the Maryland Biological Stream Survey documented Northern Two-lined Salamander (1997, 2008, and 2014) and *Pseudotriton* sp. (2008) in tributaries of the North Fork Muddy Creek, immediately adjacent to SERC (MBSS, 2015). Preferred habitats of these species vary, but in general, they inhabit streams of varying gradients containing partially submerged cover and nearby damp, closed-canopy woodlands and vernal ponds (Bruce, 1975; see Klemens, 1993). We conducted few time-constrained searches in habitats appropriate for these species. Therefore, future sampling along North Fork Muddy Creek (where suitable habitat exists) may provide a more accurate assessment of their presence at SERC.

Fowler's Toad (*Anaxyrus fowleri*) was not detected in our study, but purportedly was found at SERC in the early 1980s (J. Lynch, SERC, unpubl. data). This species is a subclimax community habitat specialist that favors early successional (pine, pine-oak, or scrub) habitats with well-drained, sandy soils and open-canopy (both permanent and ephemeral) wetlands (Klemens, 1993; Tupper & Cook, 2008). These habitats are scarce at SERC. It is possible that natural successional changes since the early 1980s may have made SERC unsuitable for this species. However, it is more likely that subadult American Toads (*Anaxyrus americanus*) were misidentified as Fowler's Toads. Therefore, we consider prior reports of Fowler's Toad unreliable in the absence of additional supporting documentation. Fowler's Toad occurs elsewhere in Anne Arundel County where its preferred habitat is more abundant (MARA, 2015)

Recently, a new species of frog, the Coughing Frog,

or Atlantic Coast Leopard Frog (*Lithobates kauffeldi*), was described (Feinberg et al., 2014). Suitable habitats for this species likely occur at SERC, but its status in Maryland is not yet determined (MARA, 2015). Analyses of recordings of Leopard Frogs at SERC were confirmed as being Southern Leopard Frog (*Lithobates sphenocephalus*) by J. Feinberg (Rutgers University, New Brunswick, New Jersey). We are currently using automated data recorders to determine if Coughing Frog exists at SERC.

Anuran Call Surveys

Anuran call surveys are an inexpensive and effective way of detecting anurans and monitoring their long-term population trends (Weir & Mossman, 2005; Weir et al., 2009; Cook et al., 2011). Our work will allow natural resource managers to initiate a citizen science-based approach to anuran monitoring. Citizen science-generated data has been useful in a variety of monitoring programs (Conrad & Hilchey, 2011; Dickenson et al., 2010). Community involvement in amphibian monitoring at SERC is necessary for monitoring to continue because there are currently no funded amphibian monitoring initiatives at SERC. We encourage readers to volunteer.

Patterns in anuran vocalization are similar to other Mid-Atlantic studies (Lee, 1973; Ernst. et al., 1997; Weir et. al., 2005; Tupper et. al 2012). However, a noticeable variation occurred in American Bullfrog. Onset of calling in this species occurred three weeks earlier (a full month earlier if we consider 2016 data; 73rd vs. 112th day of the year) in our study than was recorded at Huntley Meadows Park in Alexandria, Virginia just five years prior (Tupper et al., 2012; see also estimates of American Bullfrog detection probability by Weir et al., 2005). Onset of calling in American Bullfrog from these Mid-Atlantic studies occurred prior to, or immediately after, the earliest records of calling documented in North Carolina in 1933 (Harper, 1935). Given the more southern latitude, we would expect early records of calling in North Carolina to reflect a corresponding earlier breeding phenology. However, the earliest record reported in Harper (1935) is 19 days later than our earliest observation. Furthermore, when we compared the breeding phenologies of 10 anuran species from SERC to the same species documented at Huntley Meadows Park in 2010 and 2011, we found that 90% called earlier at SERC than they did at Huntley Meadows Park. The unexpected differences to Harper (1935) may simply be anecdotal, and the short-term differences between the breeding phenologies of anurans at SERC and Huntley Meadows Park could be due to localized environmental variation. However, the direction and magnitude of these differences (particularly in American Bullfrog) are of interest because they support a growing body of data indicating that climate warming is causing onset of anuran calling to occur earlier than formerly known because minimum thresholds for calling activity also occur earlier (Gibbs & Breisch, 2001; Parmesan & Yohe, 2003; Ledneva et al., 2004; Corn, 2005; Tupper et al., 2012). Although the precise effects of climate change on amphibians are yet to be determined, the majority of speculated consequences are negative (Gibbons et al., 2000; Corn, 2005; Parmesan, 2006). Therefore, continued long-term monitoring of anuran populations could help elucidate phenological changes that may result from climate change.

Due to infrequent, explosive patterns of vocalization, it is difficult to detect Eastern Spadefoot with standardized anuran call surveys. We detected full choruses on two occasions in 2014, but none in 2015. To more accurately monitor populations of this species at SERC, anuran call surveys should be supplemented with throw trapping of larvae. Surveyors could also deviate from the standardized calling survey protocol and visit sites when vocalization is most likely to occur (see Hansen, 1958; Klemens, 1993).

Although Cope's Gray Treefrog (*Hyla chrysoscelis*) is widespread throughout southern Anne Arundel County, Gray Treefrog (*H. versicolor*) is typically found in more northern portions of the county and areas west of the Patuxent River (MARA, 2015). We documented Gray Treefrog at SERC, but calling activity was infrequent. Only one or two individuals were detected in 2014, and this species has not been heard since. Its appearance may have corresponded with importation and planting of native shrubbery as part of a re-vegetation project in an area in front of the Mathias Wetland.

Egg Mass Counts

Egg mass counts are a cost-effective and accurate way to monitor Wood Frog and Spotted Salamander populations (Crouch & Paton, 2000; Cook & Boland, 2005; Skidds et al., 2007). In the maximum loci method (Cook & Boland, 2005), three rounds of counting are conducted across the breeding season of both species and the maximum count obtained from any of the three rounds is used as that year's tally. In the Mid-Atlantic, there is overlap between Southern Leopard Frog and Wood Frog oviposition during the latter half of the Wood Frog breeding season (Brown & Jung, 2005). It is difficult to differentiate between Wood Frog and Southern Leopard Frog egg masses. Therefore, counts

obtained from late-season samples may be unreliable. Daytime calling anuran surveys conducted early in the calling season (see Crouch & Paton, 2000) may be a better means of monitoring Wood Frog populations than egg mass counts.

We found surprisingly few Spotted Salamander egg masses after three rounds of egg mass counts at seven sites. This species is positively associated with pond hydroperiod, size, depth, and upland forest area within 1 km of breeding sites, and negatively associated with alluvium location (Skidds et al., 2007). Low abundance may be due to normal population fluctuations, lack of appropriate within-pond and upland habitat (Klemens, 1993; Egan & Paton, 2004; Skidds et al., 2007), movement of alluvial deposits (Skidds et al., 2007) associated with development of adjacent habitats, or a combination of these variables.

Wood Frog egg masses were more abundant than those of Spotted Salamander, however, over half were found at a single site (Horseshoe Bog). This site is a long-hydroperiod, temporary wetland without predatory fishes. Most of this wetland contains persistent non-woody vegetation which provided attachment substrates for many of the masses. A large portion of the wetland also contains shrub cover, which is typically not associated with Wood Frog abundance and is negatively associated with many other species. We suggest monitoring the expansion of shrub cover at this site. Ideally, at least half the wetland should remain free of woody emergent so that the physical and biological attributes remain suitable for reproduction of Wood Frog and other anurans (Volpe, 1952; Werner & Glennemeier, 1999; Skelly et al., 2002; Tupper & Cook, 2008).

CONCLUSIONS

SERC's main campus and additional parcels contain at least 93% of the anurans, 56% of the salamanders, and 53% of the reptile species recorded from Anne Arundel County, Maryland. The breeding phenology shift observed for American Bullfrog underscores the need for continued long-term monitoring. A more concentrated sampling effort in streams is necessary to detect Northern Two-lined, Northern Dusky, and Eastern Mud Salamanders. As an aside, amphibian and reptile pathogens are present at SERC (SERC unpublished data; Tupper et al., 2015). Heightened biosecurity protocols should be established (see VHS website for disinfection protocol; VHS, 2015) to reduce transmission between sites.

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LITERATURE CITED

Berven, K. A. 1990. Factors affecting population fluctuations in larval and adult stages of the Wood Frog (*Rana sylvatica*). Ecology 71: 1599-1608.

Blaustein, A. R., & D. B. Wake. 1995. The puzzle of declining amphibian populations. Scientific American 272: 52-57.

Blaustein, A. R., D. B. Wake, & W. P. Sousa. 1994. Amphibian declines: judging stability, persistence and susceptibility of populations to local and global extinctions. Conservation Biology 8: 60-71.

Brodman, R. 1995. Annual variation of breeding success of two syntopic species of *Ambystoma* salamanders. Journal of Herpetology 29: 111-113.

Brodman, R. 2002. Twelve-year study monitoring two species of pond-breeding salamanders in northeast Ohio. Ohio Journal of Science 102: 123-127.

Brown, L. J., & R. E. Jung. 2005. An introduction to mid-Atlantic seasonal pools. United States Environmental Protection Agency Mid-Atlantic Integrated Assessment. EPA/903/B-05/001. 92 pp.

Bruce, R. C. 1975. Reproductive biology of the Mud Salamander, *Pseudotriton montanus* in western South Carolina. Copeia 1975: 129-137.

Conrad, C. C., & K. G. Hilchey. 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. Environmental Monitoring and Assessment 176: 273-291.

Cook, R. P., & K. Boland. 2005. A comparison of approaches to counting Spotted Salamander (*Ambystoma maculatum*) egg masses in vernal ponds. Herpetological Review 36: 272-274.

Cook, R. P., T. A. Tupper, P. W. C. Paton, & B. C. Timm. 2011. Effects of temperature and temporal factors on anuran detection probabilities at Cape Cod National Seashore, Massachusetts, USA: Implications for long-term monitoring. Herpetological Conservation and Biology 6: 25-39.

Cook-Patton, S. C., L. Maynard, N. P. Lemoine, J. Shue, & J. D. Parker. 2014a. Cascading effects of a highly specialized beech-aphid–fungus interaction on forest regeneration. PeerJ 2:e442

Cook-Patton, S. C., M. LaForgia, & J. D. Parker. 2014b. Positive interactions between herbivores and plant diversity shape forest regeneration. Proceedings of the Royal Society B: Biological Sciences 281: 20140261

Corn, P. S. 2005. Climate change and amphibians. Animal Biodiversity and Conservation: 28.1: 59-67.

Crother, B. I. (committee chair). 2012. Scientific and standard English and French names of amphibians and reptiles of North America north of Mexico, with comments regarding confidence in our understanding. 7th Edition. Society for the Study of Amphibians and Reptiles, Herpetological Circular 39. 92 pp.

Crouch, W. B., & P. W. C. Paton. 2000. Using egg mass counts to monitor Wood Frog populations. Wildlife Society Bulletin 28: 895-901.

Davidson, E. W., M. Parris, J. P. Collins, J. E. Longcore, A. P. Pessier, & J. Brunner. 2003. Pathogenicity and transmission of chytridiomycosis in Tiger Salamanders (*Ambystoma tigrinum*). Copeia 2003: 601-607.

Dickenson, J. L., B. Zuckerberg, & D. N. Bonter. 2010. Citizen science as an ecological research tool: challenges and benefits. Annual Review of Ecology, Evolution and Systematics 41: 149-172.

Egan, R. S., & P. W. C. Paton. 2004. Within-pond parameters affecting oviposition by Wood Frog and Spotted Salamanders. Wetlands 24: 1-13.

Ernst, C. H., S. C. Belfit, S. W. Sekscienski, & A. F. Laemmerzahl. 1997. The amphibians and reptiles of Ft. Belvoir and Northern Virginia. Bulletin of the Maryland Herpetological Society 33: 1-62.

Feinberg J. A., C. E. Newman, G. J. Watkins-Colwell, M. D. Schlesinger, B. Zarate, B. R. Curry, H. B. Shaffer, & J. Burger. 2014. Cryptic diversity in metropolis: Confirmation of a new leopard frog species (Anura: Ranidae) from New York City and surrounding Atlantic Coast regions. PLoS ONE 9(10): e108213. doi:10.1371/journal.pone.0108213

Gibbons, J. W., D. E. Scott, T. J. Ryan, K. A. Buhlmann, T. D. Tuberville, B. S. Metts, J. L. Greene, T. Mills, Y. Leiden, S. Poppy, & C. T. Winne. 2000. The global decline of reptiles, déjà vu amphibians. BioScience 50: 653-666.

Gibbs, J. P., & A. R. Breisch. 2001. Climate warming and calling phenology of frogs near Ithaca New York, 1900-1999. Conservation Biology 15: 1175-1178.

Hansen, K. L. 1958. Breeding pattern of the Eastern Spadefoot Toad. Herpetologica 14: 57-67.

Harper, F. 1935. Records of Amphibians in the Southeastern states. American Midland Naturalist 16: 275-310.

Hayek, L. C. 1994. Removal sampling. Pp. 201-205 *In* W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek & M. S. Foster, (eds.), Measuring and Monitoring Biological Diversity. Standard Methods for Amphibians. Smithsonian Institution Press, Washington, DC.

Heyer, R. W. 1976. Studies in larval amphibian habitat partitioning. Smithsonian Contributions to Zoology 242: 1-27.

Heyer, R. W. 1979. Annual variation in larval amphibian populations within a temperate pond. Journal of the Washington Academy of Sciences 69: 65-74.

Higman, D. 1968. An ecologically annotated checklist of the vascular flora at the Chesapeake Bay Center for Field Biology, with keys. Smithsonian Institution, Office of Ecology, Washington, DC. 234 pp.

IUCN (International Union for Conservation of Nature). 2015. Amphibians. http://www.iucn.org/about/work/programmes/species/our_work/amphibians/. (Accessed September 2015).

Klemens, M. W. 1993. Amphibians of Connecticut and Adjacent Regions. Connecticut State Geological and Natural History Survey, Hartford, CT. 318 pp.

Ledneva, A., A. J. Miller-Rushing, R. B. Primack, & C. Imbres. 2004. Climate change reflected in a naturalist's diary, Middleborough, Massachusetts. Wilson Bulletin 116: 224-231.

Lee, D. S. 1973. Seasonal breeding distributions for selected Maryland and Delaware amphibians. Bulletin of the Maryland Herpetological Society 9: 101-104.

Lynch, J. F., & D. F. Wigham. 1984. Effects of forest fragmentation on breeding bird communities in Maryland, USA. Biological Conservation 28: 287-324.

MARA (Maryland Amphibian and Reptile Atlas). 2015. Maryland Reptile and Amphibian Database. https://webapps02.dnr.state.md.us/mara/default.aspx. (Accessed September 2015).

MBSS (Maryland Biological Stream Survey). 2015. http://streamhealth.maryland.gov/about-the-maryland-biological-stream-survey/. (Accessed October 2015).

McMahon, S. M, G. G. Parker, & D. R. Miller. 2010. Evidence for a recent increase in forest growth. Proceedings of the National Academy of Sciences (USA) 107: 3611-3615.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 37: 637-669.

Parmesan, C., & G. Yohe. 2003. A globally coherent fingerprint of climate change across natural systems. Nature 421: 37-42.

Petranka, J. W., S. S. Murray, & C. A. Kennedy. 2003. Response of amphibians to restoration of a southern Appalachian wetland: perturbations confound post-restoration assessment. Wetlands 23: 278-290.

Reed C. F. 1956. Contributions to the herpetology of Maryland and Delmarva 12: Herpetofauna of Anne Arundel County, Maryland. Journal of the Washington Academy of Sciences 47: 64-66.

Scott, N. J., & B. D. Woodward. 1994. Surveys at breeding sites. Pp. 118-130 *In* W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek & M. S. Foster (eds.), Measuring and Monitoring Biological Diversity. Standard Methods for Amphibians. Smithsonian Institution Press, Washington, DC.

SERC (Smithsonian Environmental Research Center). 2015a. Research. http://www.serc.si.edu/research/index.aspx. (Accessed September 2015).

SERC (Smithsonian Environmental Research Center). 2015b. About SERC. http://www.serc.si.edu/about/index.aspx. (Accessed September 2015).

Shaffer, H. B., R. A. Alford, B. D. Woodward, S. J. Richards, R. G. Altig, & C. Gascon. 1994. Quantitative sampling of amphibian larvae. Pp. 130-141 *In* W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek & M. S. Foster (eds.), Measuring and Monitoring Biological Diversity. Standard Methods for Amphibians. Smithsonian Institution Press, Washington, DC.

Skelly, D. K., L. K. Freidenburg, & J. M. Kiesecker. 2002. Forest canopy and the performance of larval amphibians. Ecology 83: 983-992.

Skidds, D. E., F. C. Golet, P. W. C. Paton, & J. C Mitchell. 2007. Habitat correlates of reproductive effort in Wood Frogs and Spotted Salamanders in an urbanizing watershed. Journal of Herpetology 41: 439-450.

Szlavecz, K, M. McCormick, L. Xia, J. Saunders, T. Morocol, D. Whigham, T. Filley, & C. Csuzdi. 2011. Ecosystem effects of non-native earthworms in Mid-Atlantic deciduous forests. Biological Invasions 13: 1165-1182.

Tupper, T. A., R. Aguilar, A. Ferrara, & C. Hay. 2015. Observations of snake fungal disease in *Nerodia sipedon* in Anne Arundel County, Maryland. Catesbeiana 35: 37.

Tupper, T. A., & R. P. Cook. 2008. Habitat variables influencing northern clade *Bufo fowleri*: implications for conservation. Applied Herpetology 5: 101-119.

Tupper, T. A., T. Galitizin, C. Bozarth, & D. M. Lawlor. 2012. Patterns of frog and toad vocalization in Fairfax County, Virginia. Banisteria 39: 34-46.

VHS (Virginia Herpetological Society). 2015. Infectious diseases of our native herps and disinfection protocols. http://virginiaherpetologicalsociety.com/disease/index.htm. (Accessed September 2015).

Vitt, L. J. & J. P Caldwell. 2013. Herpetology: An Introductory Biology of Amphibians and Reptiles. Academic Press, London. 776 pp.

Volpe, E. P. 1952. Physiological evidence for natural hybridization of *Bufo americanus* and *Bufo fowleri*. Evolution 6: 393-406.

Weir, L. A., & M. J. Mossman. 2005. North American Amphibian Monitoring Program (NAAMP). Pp. 307-313 *In* M. J. Lannoo (ed.), Amphibian Declines: The Conservation Status of United States Species. University of California Press, Berkeley, CA.

Weir, L. A., I. J. Fiske, & J. A. Royle. 2009. Trends in anuran occupancy from northeastern states of the North American Amphibian Monitoring Program. Herpetological Conservation and Biology 4: 389-402.

Werner, E. E., & K. S. Glennemeier. 1999. Influence offorest canopy cover on the breeding pond distributions of several amphibian species. Copeia 1999: 1-12.

Whiles, M. R., K. R. Lips, C. M. Pringle, S. S. Kilham, R. J. Bixby, R. Brenes, S. Connelly, J. C. Colon-Gaud, M. Hunte-Brown, A. D. Huryn, C. Montgomery, & S. Peterson. 2006. The effects of amphibian population declines on the structure and function of Neotropical stream ecosystems. Frontiers in Ecology and the Environment 4: 27-34.

Wright, A. H.., & A. A. Allen. 1909. The early breeding habits of *Ambystoma punctatum*. American Naturalist 43: 687-692.

Wright, A. H., & A. A. Wright. 1949. Handbook of Frogs and Toads of the United States and Canada. Cornell University Press, Ithaca, NY. 640 pp.

Wyman, R. L. 1990. What's happening to the amphibians? Conservation Biology 4: 350-352.

Young, S., L. Berger, & R. Speare. 2007. Amphibian chytridiomycosis: strategies for captive management and conservation. International Zoo Yearbook 41: 85-95.

Appendix 1. Sites, abbreviations, location, and general pool type. Hog New, Vernal, and Main are collectively Hog Complex.

Site	Abbreviation	Lat	Long	Pool Type
Beaver Pond	BEPO	38°53' 27.79"	76°33'23.69"	Beaver
Camp Letts Pond	CALE	38°54' 19.26"	76°32'15.71"	Natural
CO2 Marsh	CO2	38°52' 21.66"	76°32'44.66"	Natural
Construction Pond	COPO	38°53' 14.10"	76°33'21.29"	Artificial
Contees Wetland	CONTE	38°53' 38.14"	76°32'53.66"	Natural
Glebe Bog	GLEBE	38°54' 00.04"	76°33'18.84"	Natural
Fox Point	FOPO	38°52' 55.84"	76°32'56.67"	Natural
Hog Main	HOMA	38° 52' 50.28"	76° 33' 05.08"	Natural
Hog New	HONE	38° 52' 55.29"	76° 33' 16.44"	Natural
Hog Vernal	HOVE	38° 52' 52.78"	76° 33' 07.88"	Natural
Horseshoe Bog	HOSH	38° 52' 18.75"	76° 33' 20.25"	Natural
Mathias Wetland	MATH	38° 53' 15.95"	76° 33' 17.24"	Artificial
Mill Swamp	MISW	38° 53' 01.20"	76° 34' 15.98"	Natural
North Fork	NOFO	38° 53' 37.09"	76° 33' 37.12"	Natural
O'Neill Marsh	ONEIL	38° 52' 44.68"	76° 33' 46.37"	Natural
Retaining Pond	RETAIN	38° 53' 18.38"	76° 33' 04.39"	Artificial
Snake House Wetland	SNHO	38° 53' 29.34"	76° 33' 37.22"	Natural

Appendix 2. Species abbreviations, and common and scientific names. Nomenclature follows Crother (2012).

Abbreviation	Common Name	Scientific Name
AMTO	American Toad	*Anaxyrus americanus*
BOTU	Eastern Box Turtle	*Terrapene carolina*
BUFR	American Bullfrog	*Lithobates catesbeianus*
CGTF	Cope's Gray Treefrog	*Hyla chrysoscelis*
CHFR	Upland Chorus Frog	*Pseudacris feriarum*
CRFR	Eastern Cricket Frog	*Acris crepitans*
DBTE	Diamond-backed Terrapin	*Malaclemys terrapin*
FLSK	Common Five-lined Skink	*Plestiodon fasciatus*
FTSA	Four-toed Salamander	*Hemidactylium scutatum*
GASN	Common Gartersnake	*Thamnophis sirtalis*
GRFR	Green Frog	*Lithobates clamitans*
GRTF	Green Treefrog	*Hyla cinerea*
KISN	Eastern Kingsnake	*Lampropeltis getula*
MASA	Marbled Salamander	*Ambystoma opacum*
MUDT	Eastern Mud Turtle	*Kinosternon subrubrum*
MUSK	Eastern Musk Turtle	*Sternotherus odoratus*
NBSN	Dekay's Brownsnake	*Storeria dekayi*
NGTF	Gray Treefrog	*Hyla versicolor*
NWSN	Common Watersnake	*Nerodia sipedon*
PATU	Painted Turtle	*Chrysemys picta*
PIFR	Pickerel Frog	*Lithobates palustris*
RACER	North American Racer	*Coluber constrictor*
RASN	Eastern Ratsnake	*Pantherophis alleghaniensis*
RBSA	Eastern Red-backed Salamander	*Plethodon cinereus*
RBTU	Northern Red-bellied Cooter	*Pseudemys rubriventris*
RESL	Red-eared Slider	*Trachemys scripta elegans*
RGSN	Rough Greensnake	*Opheodrys aestivus*
RISN	Eastern Ribbonsnake	*Thamnophis sauritus*
RNSN	Ring-necked Snake	*Diadophis punctatus*
RSNE	Eastern Newt	*Notophthalmus viridescens*
SESN	Smooth Earthsnake	*Virginia valeriae*
SLFR	Southern Leopard Frog	*Lithobates sphenocephalus*
SNTU	Snapping Turtle	*Chelydra serpentina*
SPPE	Spring Peeper	*Pseudacris crucifer*
SPSA	Spotted Salamander	*Ambystoma maculatum*
SPTO	Eastern Spadefoot	*Scaphiopus holbrookii*
SPTU	Spotted Turtle	*Clemmys guttata*
WOFR	Wood Frog	*Lithobates sylvaticus*
WOSN	Common Wormsnake	*Carphophis amoenus*